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A METHOD OF MAPPING RETINAL CIRCULATION BY PROJECTION.[1]

By R. M. OGDEN, B. S.

The object of this investigation was to study the entoptic phenomena of blood movement in the retina, and to obtain maps by an introspective method which should indicate the course of the vessels in as satisfactory a manner as possible. Numerous superficial observations have been made along this line, but reference to physiological and psychological literature failed to bring to light any detailed maps of the blood movement as observed subjectively upon a bright field. Maps in varying degrees of satisfaction have frequently been traced by many of the 'shadow methods,' *i. e.*, by actual projection of the vessels upon a screen. These, however, reproduce only the larger vessels with any degree of definiteness, and do not indicate the direction of the blood flowing through them. This method is here employed only as a means of verifying the other work.

§ 1. HISTORICAL.

The perception of the phenomena of blood movement in the eye seems to have first been described by R. W. Darwin in 1786. Darwin states that he could see these movements when gazing at the sky or some other bright field, after holding his breath and rubbing his eyes. The experiment was thus facilitated by an increase in the amount of blood sent to the eye. He believed the appearances to be dependent on the general state of the observer's health, and to be most distinct after the eye became fatigued.[2]

[1] From the Psychological Laboratory of Cornell University.
[2] C. J. Burch: The Retinal Circulation, *Nature*, LIII, 558.

In 1819 J. E. Purkinje published his observations,[1] and noted that the retinal circulation might be observed subjectively under certain conditions. By directing the attention on a clear flash of diffused light, he could see bright spots appearing in continuous courses which emerged at irregular intervals at the same points, completed their courses, and disappeared. Purkinje also laid down a method for projecting the vessels as shadows. This he accomplished in a dark room, by directing a strong light on the sclera. When the light was moved slightly from side to side, the vascular shadows became visible in the glare before the eye.

J. Mueller called attention to these blood movements in his Handbuch der Physiologie des Menschen, published in 1840 (II, 390). He indicated that an expression of such movements might be observed by glancing at a bright even-toned field, such as the sky, a patch of snow, or a white paper uniformly illuminated by a steady light. He saw nothing save confused movements, which rushed towards one another and passed one another in irregular smoke-like courses. Mueller considered it impossible to determine the direction of the movement. He accepted it as a manifestation of the retinal circulation. In addition, he noted certain definite phenomena occurring when one stoops and rises again suddenly, which he attributed to congestion caused by the ebb and flow of the blood. These movements were described as a "leaping" of dark bodies in various directions over the field.

O. N. Rood, in an article published in 1860,[2] states that by gazing intently at the bright sky or other illuminated field through three plates of cobalt glass he was able to obtain a view of "small bodies like animalcules" which travelled over the field in all directions. The spots seemed to be yellowish in color, and appeared elongated in the direction of their motion. A convex lens held before the eye did not alter the occurrences, a fact which indicated that these movements were situated in the retina. Near the axis of vision, the moving body seemed always to pursue the same direction, and to disappear at the same point. Rood concluded that these phenomena were probably due to blood corpuscles.

These bodies may also be observed through a certain thickness of a solution of cupro-sulphate of ammonia, though not as perfectly as with the cobalt glass. Through red, orange, yellow, green or purple media they are still less distinct. Rood advanced a theory, in explanation of these appearances, as follows. The blood discs are yellow, and therefore opaque to blue and violet light. They, consequently, cast shadows when such media are interposed. But since the retina is strongly impressed with blue light, the portions protected by the corpuscles experience a complementary sensation, and instead of a dark shadow, a yellowish moving speck results. Since yellow media are transparent to red, orange, yellow and green lights, no very perceptible shadows are cast when these are employed.

In another article,[3] published a few months later, some additional observations were noted, mainly the facts that faint indications of movements may be seen with the naked eye, and, further, that the moving bodies are sprinkled over the field, and do not appear in compact masses. Quoted in Rood's paper are some of the results of W. B. Rogers. Following Darwin and Mueller, in their observation that

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[1] Beobachtungen u. Versuche zur Physiologie d. Sinne, I, Prag, 127.
[2] The American Journal of Science, XXX, 2nd series, 264.
[3] *Ibid.*, 385.

the phenomenon is facilitated by an increase in stimulation of the retinal blood supply, Roger maintains that after continued effort of vision, active exercise, or other stimulation of the circulation, these dots are readily seen in broken curves, which come and go in such a manner as to indicate the presence of certain prescribed and permanent channels. As one continues to fixate a bright field, a shade covers one's vision, and one sees, upon a dark background, innumerable streams of particles which move in loops and curves and retain a constant pattern. These courses have a "tawny yellow tint," and last only one or two seconds. The shade passes, and returns after an interval, though the courses are then less distinct.

Rogers indicates several methods for obtaining this projection:

(1) gazing through a black paper tube at a white surface till the eye is fatigued and greatly excited;

(2) gazing for a few seconds into a pocket microscope held at about focal distance from the eye;

(3) a method previously indicated by Purkinje: the light of a spirit-lamp, with a salted wick which gives an intense yellow flame, is concentrated on the eye by a convex lens of three-inch focus. The bright field thus observed soon resolved itself into a mass of small, round, densely-packed moving bodies which appeared light against a darker ground. They seemed "packed together like a fine mosaic," but their paths could be traced as they moved at a slow uniform rate through the narrow channels. Rogers adds that if yellow plates of glass were interposed the bodies appeared more distinctly. He attributes the indistinct vision, which is concomitant with eye-weariness and faintness, to an increased congestion in the vessels.

Helmholtz in his Optics[1] reviews the subject, and states that Vierordt saw a rushing movement when he agitated his spread fingers before his eyes. This movement was attributed by the observer to retinal circulation. Helmholtz affirms that neither Meissner nor he himself has been able to see such movements; they find only an appearance of "shoreless streams." However, he does not question Vierordt's phenomenon or its explanation. The observations of Purkinje and Mueller are also cited, and, in the light of these, with the directions furnished by Rood, Helmholtz concludes that the phenomenon undoubtedly proceeds from blood movements in the retina. In explanation, he advances the theory that the corpuscles become jammed together in large masses in the smaller vessels, so that the portion of the capillary tube ahead of the check is emptied. At last this blockade is released, and the whole mass moves quickly on. This causes the appearence of definite movement through certain restricted portions of the smaller vessels. Similar phenomena are observed in capillary circulation under the microscope. Helmholtz concludes that the bright spots observed should be considered as the optical expression of "little stoppages" in the retinal blood flow, which occur only in certain narrow passages of roots of vessels.

Landois and Stirling[2] cite Boisser as advancing the theory that the appearances may be caused by the red blood corpuscles in the capillaries. These, acting as small light-collecting discs, concentrate the rays falling on them from without, and throw the light upon the rods of the retina. In order to accomplish this, each corpuscle must be in a special position,—probably with its broad face toward the light. If it rotates, the phenomenon disappears. This theory is interesting, but (as will be shown later) the facts of observation and histology do not substantiate it.

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[1] Handbuch der physiologischen Optik, 2nd ed., 1896, 198.

[2] Manual of Human Physiology, 1895, II, 995.

§ 2. Experimental.

Method. After a careful consideration of the methods indicated in the literature, a simple proceeding was adopted as follows. A rectangular screen, 67x87 cm., of even-surfaced, white, translucent paper was erected in a window facing the western sky, the light from which was unobstructed by trees or other objects. This screen was marked off in squares of 2 cm., and at the center was placed a fixation-point. Before the screen a desk was arranged with drawing-board, on which were placed papers with cross rulings like those on the screen, which brought the eye in a line with, and 92 cm. distant from, the fixation point. An adjustable chair for the observer, blue glasses for media, and shades for the unused eye completed the apparatus. Each observer worked with the right eye, the left being comfortably shaded so as not to interfere with the vision of the other. Observations were made both through the blue glass and with naked vision. The moving points were observed, and their tracks carefully noted by aid of the arrangement of squares, and then transferred to the map.

In attempting to check or verify the results obtained in this way, all the classical methods of shadow-projection were investigated. To enumerate a few:

(1) In a dark room a candle is held near the eye which regards the distance. The vascular courses are supposed to appear as dark lines on a yellowish background. These courses come out distinctly when the candle is moved.[1] This method was tried, but no very satisfactory results were obtained.

(2) The Purkinje method. A strong light is focussed on the sclera at a distance as far as possible from the cornea. When the light is moved slightly from side to side, the courses appear before the eye. This method requires delicate handling, owing to the burn and the general strain caused by the focussing of a strong light upon the eye. No very satisfactory phenomena were observed, and the method was not found to be practical as a means of verification.

(3) W. C. Ayres[2] has enumerated several methods involving modifications of those already described. The most important requires a dark room, and an even, constant source of light. This light is reflected through the pupil on to the retina by means of such dull reflectors as a gold ring or a teaspoon bowl. The shadows are thus projected as in the other methods. Ayres can see them very distinctly on a white card held a short distance from the eye, and has been able to trace a map of the macular region which is surprisingly intricate in detail and regular in contour.

A close examination of Ayres' map, however, discloses the fact that only 12 courses were traced with any definiteness. The fine net-work of anastomoses between these is arbitrarily indicated. He is able to note the fovea roughly, but states that he cannot differentiate veins from arteries, though at times he perceives some indication of the direction

[1] B. A. Randall, in de Schweinitz, Am. Text Book of Diseases of the Eye, Ear, Nose and Throat, 1889, 140.

[2] In *Archiv. f. Augenheilkunde*, Wiesbaden, 1884, XIII, 29.

of blood-flow. With this method, as with the method from which it is derived, it is necessary to keep the light on the retina in motion, by a side movement either of the reflector or of the head. This, of course, introduces an error in judgment when one attempts to map the vessels. We attempted to reproduce Ayres' results, with a trained observer, but our success was slight, owing to the great difficulty experienced in directing the proper light upon the retina.

(4) The second Purkinje method has already been outlined as it was worked out by Rogers. We repeated the experiment, and noted the movements described; but they were not nearly so numerous as those obtained by gazing at the bright sky, nor as satisfactory, owing to the very limited field which the lens allows. We also noticed that muscæ volitantes appeared frequently and proved distracting, as it was hard to differentiate them from the vascular courses.

(5) The method adopted is the simplest and for many reasons the best of those which the literature indicates.[1] It consists in glancing through a moving pinhole or steropaic opening toward an evenly illuminated screen. Both openings were employed, but the steropaic has the advantage, since by agitating it in various directions considerable portions of the retinal field are exposed. Vertical movements when the opening is held horizontally bring out the transverse courses; horizontal movements with a vertical opening show the longitudinal vessels. They appear fully as definitely as Ayres' courses. The fovea is not normally projected, nor is there any indication of the direction of the movement; but both these points are satisfactorily given by our working method. It is, accordingly, with this verificatory method that we are concerned, the rest having been discarded as more complex and in general less satisfactory.

It may be of interest to note that an investigation was made into the possibility of obtaining a photograph of the retinal vessels. The literature upon this subject was worked over, and a number of methods studied, but it was found that the experiment is as yet too primitive to furnish any satisfactory record of the smaller vessels or capillaries. Since these are the courses of main importance in the present work, the idea of photographing the retina was abandoned.[2]

§ 3. Introspective Results.

Maps were obtained from four observers in the manner detailed. The general characteristics of their observations were uniform and not greatly at variance with the results obtained

[1] de Schweinitz, 140.

[2] C. Panel: D'un moyen pratique de photographier le fond de l'oeil. Paris thesis, 1887.

W. Thorner: Ueber d. Photographie d. Augenhintergrundes. Berlin thesis, 1896.

G. Aarland: Internationale medizinische-photographische Monatsschrift. Leipzig. II, 1895, 4.

Ludwig Jankau, in same volume, 18.

A. E. Fick: Bericht ü. d. zwanzigste Versamm. d. ophthalmologischen Gesell. Heidelberg, 1899. XXVII, 197.

Th. Guilloz, in Revue medicale de l'est. Nancy, 1895. XXVII, 212.

by the authorities above quoted. Two of our observers gained their most satisfactory data after interposing a blue glass between the eye and the field of vision. The other two worked for the most part with the naked eye. It was noticed that the dots were less plentiful but slightly more distinct when seen through the blue glass. This may be accounted for by the fact that on the blue field there seems to be a darker ring about the spots, which aids to differentiate them from the background. Retinal rivalry caused by the black screen over the left eye was experienced to some extent by all the observers, but it was quickly overcome, and did not return after the first few sittings.

The more detailed notes made by the observers, whom we shall designate as *B* (Mr. T. Bliss), *W* (Dr. M. F. Washburn), *C* (Miss J. A. Cochran) and *O* (Mr. R. M. Ogden), are as follows.—*B* procured the most elaborate map of all. He is a careful, patient observer, and seemed to obtain, without trouble, definite courses over all parts of the field of vision. The more remote courses were usually longer and perhaps less fine in detail; still they repeated themselves frequently, and seemed to offer little difficulty as to their exact position.

Throughout the field *B* differentiated the appearances into two classes. (1) As to motion: there seemed to be a class of spots (*a*) which moved very rapidly through a considerable distance, and merely indicated their general direction. These were, for the most part, situated beyond the macular region. Their courses appeared as mere curves or straight lines. There was also a class (*b*) of slower moving spots, whose courses were more definite. They traversed shorter distances than the others, and were situated for the most part about the macula. (2) As to color: *B* used the blue glass exclusively, and observed spots both lighter and darker than the background. The lighter spots were the largest and most numerous. In general, they appeared to have dark borders and to be of a faint bluish tinge. The darker spots were smaller, less distinct, and infrequent. *B* has also seen spots which appeared at first as dark shadows. As they approached the center of the field they brightened for a brief interval, then darkened, and finally disappeared as they came.

The phenomena which are supposed to result from fatigue, as described by Rogers, were all carefully noted by *B*. His results demonstrate that such appearances could be seen, but not at all frequently, nor in a very satisfactory manner. By gazing through a black tube at a bright field he noted one course like a white line. This may have been a particle in the humor, since such bodies not infrequently appear as white, thread-like lines. Courses of the same type, together with a general movement over the field like a gentle ripple of water, were seen when glancing through a lens held against the sky. Two courses thus picked out were checked on the other map. Similar projections were obtained by squinting the eye and glancing toward the screen without the mediation of tube or lens. These may also have been caused by muscæ volitantes, or by shadows cast by the eye lids or eye lashes.

W worked exclusively with the naked eye. Through all her experimentation she has been unable to procure very satisfactory courses in the right portion of the visual field. She obtains a number of well-defined paths, which constantly repeat themselves, in the region roughly indicated as from 8 to 18 cm. to the left of the fixation point upon the projection screen. These are so far removed from the center

that it is impossible to check them by shadowing the vessels themselves. Several expedients, such as cutting off the light from the left portion of the field, were resorted to, in the hope of forcing the attention on the right half; but they proved of no avail except, perhaps, to bring out the macular capillaries somewhat more clearly. By stimulating the left eye, in which *W* could see movements on the right or nasal side, and then changing to the right organ, we were able to bring out a few slight movements in the smaller vessels to the right of the fixation point. At last, by the use of a stationary pinhole through which the screen was fixated, a few satisfactory tracks about the center were procured. This restriction in the phenomena of circulation in *W*'s eye can be attributed only to a persistent habit of attention which seemingly cannot be overcome. The courses to the left of the field run through considerable distances, but are not noted with any of the fine detail which the vessels themselves are known to possess. Yet the general direction of the flow is definitely mapped, and, by reason of numerous repetitions of the same movement, we must accept the tracks as fairly accurate.

The nature of the spots themselves was usually lost in the observation of their movement. At times, however, elliptical or circular spots were described, which were generally lighter than the surrounding field, and possessed an irregular, dark border. The paths near the macula were more definite and perhaps more rapid than the others.

C's results were greatly handicapped by a fatigue which always set in early in the test, and put an end to reliable tracing. This fatigue caused the appearances to be blotted out entirely, and was accompanied by a distinct loss in power of concentration. The increase in the stimulation of the retinal flow, which has been noted as attendant on fatigue of the organ, was thus discounted and rendered useless. *C*'s best results were obtained with blue media. In regard to the character of the dots, she made the same general differentiation as *B*, viz.: that small, slow-moving dots operate near the macula, while larger, clearer specks move in a rapid, jerky manner through the remoter parts of the field. The tracks mapped about the fixation-point were frequently repeated, and in many cases checked with the actual vascular projection. Those further out in the field were for the most part indefinite.

O gained his most definite results in the macular region. There were times when movements in the periphery were noted, but they were not reproducible except as to general direction. Fatigue usually occurred after from 15 to 20 minutes' observation, and was accompanied by diminution of attention which rendered further experiment difficult. Many more courses were seen without the blue glass than with it, but they were not so distinct. *O*'s best results were obtained by a successive use of the two methods. In general, the spots were brighter than the background, though occasionally vague, moving shadows were perceived. Movements were commonly more rapid in the periphery. Courses varied in length from mere flashes to clearly defined tracings. The spots were devoid of color, save when the blue glass tinged them with its hue. On a bright day the spots sometimes had dark centers, and darker borders surrounding a light ring. The shape was not definitely noted, but seemed to be regular in contour.

O reported the following interesting phenomenon. "One day, when I was removing a dark screen before the window, I glanced at the field, and saw it filled with round, intensely bright spots, distinctly larger than usual. They darted about at a very rapid rate. This only continued for a moment, and, as the eyes became adapted to the light, the spots dissolved into the type of spots normally observed." It

seems possible that this occurrence was due to the suddenly increased stimulation of the retina when the pupil was much dilated.

§ 4. Conclusion.

This study has demonstrated that with a fair amount of patience and attention one may secure a satisfactory map of the movements of the blood through a considerable area about the region of the *macula lutea*. Patience and attention are essential, in view of the numerous objective sources of error. It is very difficult to maintain a fixation-point. When the eye slips away, the courses are materially displaced upon the projection plane. This is particularly noticeable with the method for projecting the shadows of the vessels, in which the observer views the field by intermittent light.

Any increase in the stimulation of the blood supply should produce a corresponding increase in these manifestations, as has been noted by many writers. But for definite and careful observation such increased stimulation is usually of no avail, since under the conditions the attention is at a very low ebb.

The physical basis for these movements is undoubtedly to be found in some peculiarity in the behavior of the blood corpuscles. The Rood theory, before mentioned, is based upon the supposed yellow coloration of the spots. *Not one of our observers could detect any yellowness.* This fact seems sufficient to render the theory untenable.

The Boisser theory has certain attractive features. Its assumption of the action of single corpuscles in focussing light upon the retinal rods will account satisfactorily for those isolated, sudden flashes of brightness which most of our observers reported. On the other hand, certain histological facts speak against this theory. The red blood corpuscles are bi-concave, and differ very slightly in density from the lymph which surrounds them. They are, therefore, calculated to disperse rather than to collect rays of light, if they have any refractile power at all.

The Helmholtz theory treats the phenomenon as the "visual expression of little stoppages" in the capillaries, which cause an emptying in that small portion of the vessel which immediately precedes the obstruction. These brief interstices conduct the light to the rods, and, by contrast with the surrounding field, produce the phenomena of bright dots. Histology demonstrates that brief checks in the blood-flow occur at times and may be caused in either of the following ways: (1) the corpuscles jam into, and pile up in, certain narrow vessels; (2) corpuscles often catch for an instant at the point where a vessel branches, and so produce a momentary stoppage. Helmholtz attributes the observed movements to the first of these

causes, and notes that the phenomena occur only in "certain narrow passages of roots of vessels." Our method, however, has clearly demonstrated that the majority of movements observed take place in vessels of an appreciable size, since they can be readily 'shadowed.' It furthermore seems difficult to believe that an empty space could precede a mass of corpuscles through such long distances as are frequently noted. The mass, when released, should spurt on, quickly filling the near intervening spaces.

It seems more plausible to connect these 'stoppages' with certain brief, jerky flashes which are noted through the field of vision, and to attribute the more prominent phenomena to chance spaces between corpuscles or bundles of corpuscles in the normal flux. The latter appearances may be in some manner aided by a varying refractile power of different portions of the vascular walls. We cannot note this as a fact, but the consensus of opinion among our observers favors the idea that the dots continually repeat themselves through the same portion of a vessel.

The fact of movement is noted before the shape or form of the moving body is perceived. But a careful introspection demonstrates conclusively that the definite, more numerous bodies always appear brighter than the surrounding field, and are regular in contour. We are thus limited to Boisser and Helmholtz for our explanation; but, as has been shown, the two theories admit of considerable criticism. After eliminating all errors, the Helmholtzian notion is perhaps most easily modified into a form which will comprehend our results. The spots are bright; they must, therefore, be conditioned by the passage before the retinal elements of media which readily transmit light. We know that spaces occur between bundles of corpuscles. When the external light pierces such an interstice, the rods behind it will be subjectod to an increased stimulation throughout the distance through which such a space retains its character. This little flash of brightness is then projected in a more or less circular form, and, by contrast with the surrounding field, appears as a light moving dot.

The darker rings and centers, following shadows, and gray appearances in general, may all be attributed to the brief, vague shadows of the corpuscles themselves, when they are collected in considerable numbers. They usually precede or follow the bright inter-spaces.

The rate of movement appears to be determined for the most part by the character of the vessel. Brief stoppages in the flow may offer some slight differentiation from the normal motions. Nearly all our observers note short, jerky movements which might be attributed to such checks in the flow. Yet, as a rule,

the rate of movement is so irregular that we cannot state with exactness when the phenomena should be attributed to a check in the flow, and when to a mere separation of bodies in their course.

Peripheral motion has been judged by one of our observers as faster, by another as slower, than central. The macular vessels are smaller than those in the periphery; therefore the flow would move most slowly in the macular region. But it is difficult to note the details of a movement which takes place in indirect vision. For this reason the courses in the borders of the screen are reported merely as movements in a certain direction, whereas the nature of the paths which are projected near the fixation-point can be reported with great detail.

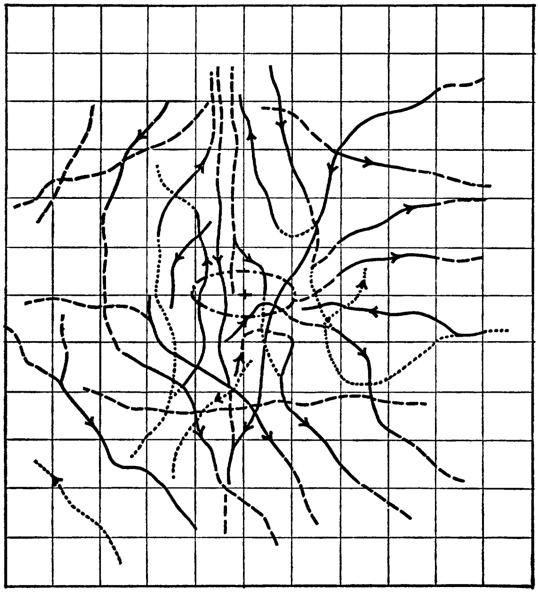
The Maps.

Continuous black lines represent courses obtained by the appearance of moving bodies upon the screen, and checked by the projection of shadow courses in the same position.

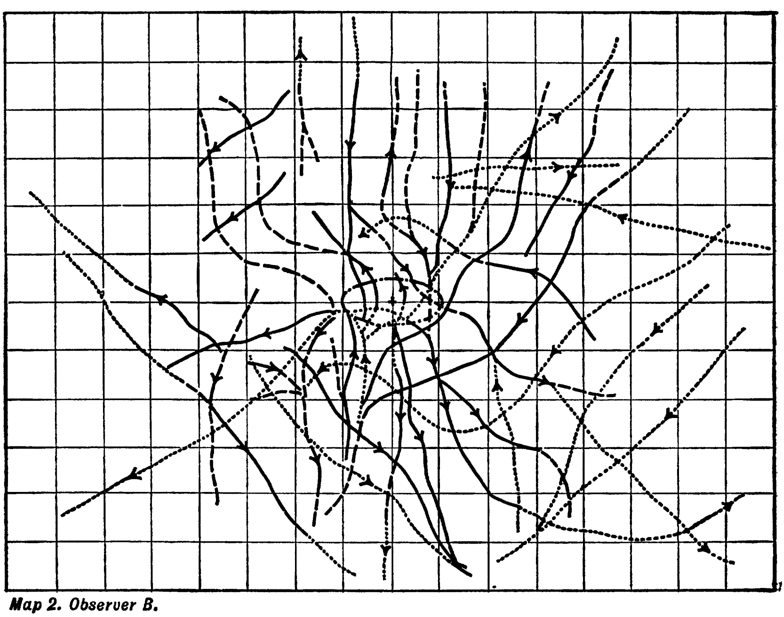
Dotted lines represent courses obtained in the same manner and many times repeated, but not verified by the shadow projections. This indicates in general that they are very fine vessels which have been overlooked or are too small to appear projected as shadows.

Broken lines represent definite courses which appeared with use of the moving pin-hole or slit opening, but through which no movements have been observed.

The elliptical figure about the fixation-point represents the macula lutea.



Map 1. Observer O.



Map 2. Observer B.